Deep Phreatic Thermal Explorer:

Robotic Exploration and Biologic Sampling in 3D Unexplored Environments

DEPTHX

THE UNIVERSITY OF TEXAS AT AUSTIN

THE UNIVERSITY OF ARIZONA
TUCSON ARIZONA

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER

Colorado
University of Colorado at Boulder

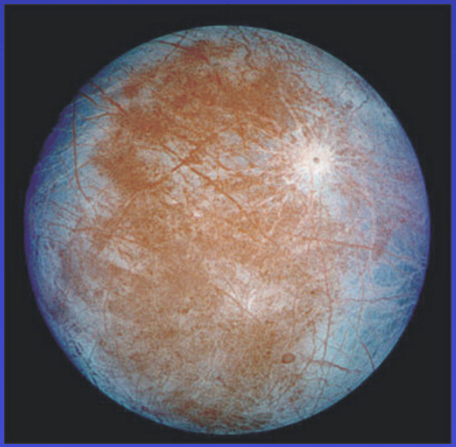
STONE AeroSPACE

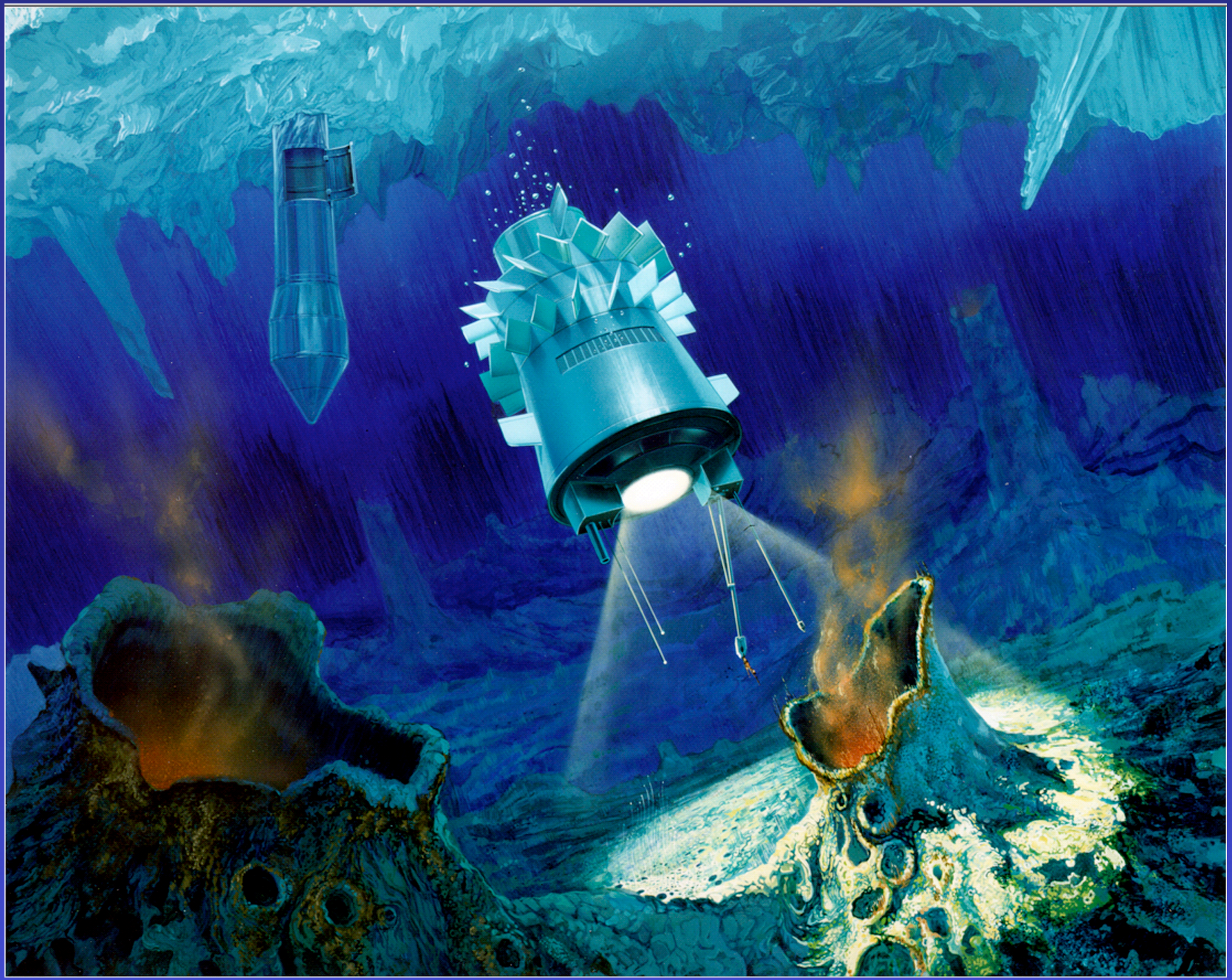
Carnegie Mellon

Southwest Research Institute

Path to mission Overview

- Zacatón (DEPTHX)
- Lake Vostok
- Europa





DEPTHX’s ASTEP Goals

- Astrobiology Science Goal: Develop an advanced methodology and protocol for the discrimination of life in a sub-aqueous environment.

- Planetary Exploration Goal: Develop the DEep Phreatic THermal eXplorer (DEPTHX) vehicle, an autonomous maneuvering platform that acts upon the information sensed and processed by the hierarchical decision-to-collect microbiological subsystem and “drives” the sensor suite to areas of potential interest.

Relevance to ASTEP

DEPTHX directly addresses the ASTEP Program's need for technology maturation, science data collection, and operations analysis in the areas of:

- Self-contained mobile science systems and platforms
- Instrument suites for *in situ* identification and analysis of biomarkers
- Integration of science instrument suites with mobile platforms
- Autonomous instrument deployment and placement
- Autonomous recognition of unexpected science phenomena
- Characterization of life-supporting environments

DEPTHX Overview

- Fully Autonomous (AUV)
- Bio-sampling Subsystem
- DEPTHX Vehicle Heritage
- 3D Real-time Subterranean Imaging
- SLAM navigation
- Mission Executive

Microbiology Decision-to-Sample Hierarchy

STAGE	GOAL	APPROACH	SENSORS	HARDWARE /ALGORITHMS
World Exploration	Map the extent of uncharacterized world	Build up 3D spatial map of world boundary	Sonar mapper, pressure (depth), inertial guidance, RLG, Doppler sonar	3-D SLAM, Physical Platform, maneuvering thrusters
World Characterization	Measure significant parameters that are indicators of likely places for concentrated search	Volume-controlled raster sweep spatial mapping of chemical and environmental parameters and construction of onboard lookup tables.	Coarse-scale microprobe suite including, but not limited to: sulphur (sulphate/ sulphide); pH; temperature, organic carbon, dissolved oxygen, flow, dissolved hydrogen.	data analysis

Microbiology Decision-to-Sample Hierarchy

STAGE	GOAL	APPROACH	SENSORS	HARDWARE /ALGORITHMS
High Level Region Discrimination	Identify likely regions of interest	Data mine chemical and environmental data in the context of the 3D world model.	none	Onboard parallel processing to prioritize 3D volume zones for further analysis and data collection
Localized Site Characteri-zation	Refine knowledge of "interesting" region candidates	Use high resolution instruments to further prioritize localized likely site. Intelligent, adaptive analyses of the environment, e.g. move platform along gradients.	High res cameras and multi-spectral lighting (RGB, UV), ultrasound, fine-scale microprobe suite, wall and/or floor compliance.	Implement fuzzy rules of what's "interesting" (adaptive as we learn more about what is "interesting" for the local region), image processing, robot arm. Binary go/no-go decision for further investigation.

Microbiology Decision-to-Sample Hierarchy

STAGE	GOAL	APPROACH	SENSORS	HARDWARE /ALGORITHMS
In-situ Analysis	Detect life forms in candidate samples	Position and maintain platform on site. Acquire candidate sample. Test for presence of cells using imaging, fluorescent probes, and wet chemistry.	High resolution imaging (200×) with multispectral light; ATP sensor with lucifirin/luciferase assay; molecular probes for flagella, lipids, storage compounds (PHB), and exo-polysacharides; flow-through imaging (fluorescence segmentation).	Fine-scale robot arm; sampling probe, flow pump; machine vision hardware and software; sample- collect decision algorithm
Collection	Collect and Return samples asepticall y	Capture from the fluid column, the wall surface, underlying matrix (rock), and/or floor sediment.	Contact sensors; force sensors; flow sensors; “full” sensors.	Robot arm; coring tool; 1 ml × 10 sample carosel; 15 ml × 10 sample carosel.

Deep Phreatic Thermal Explorer:

Robotic Exploration, Mapping, and Life Search at the World's Deepest Cenote

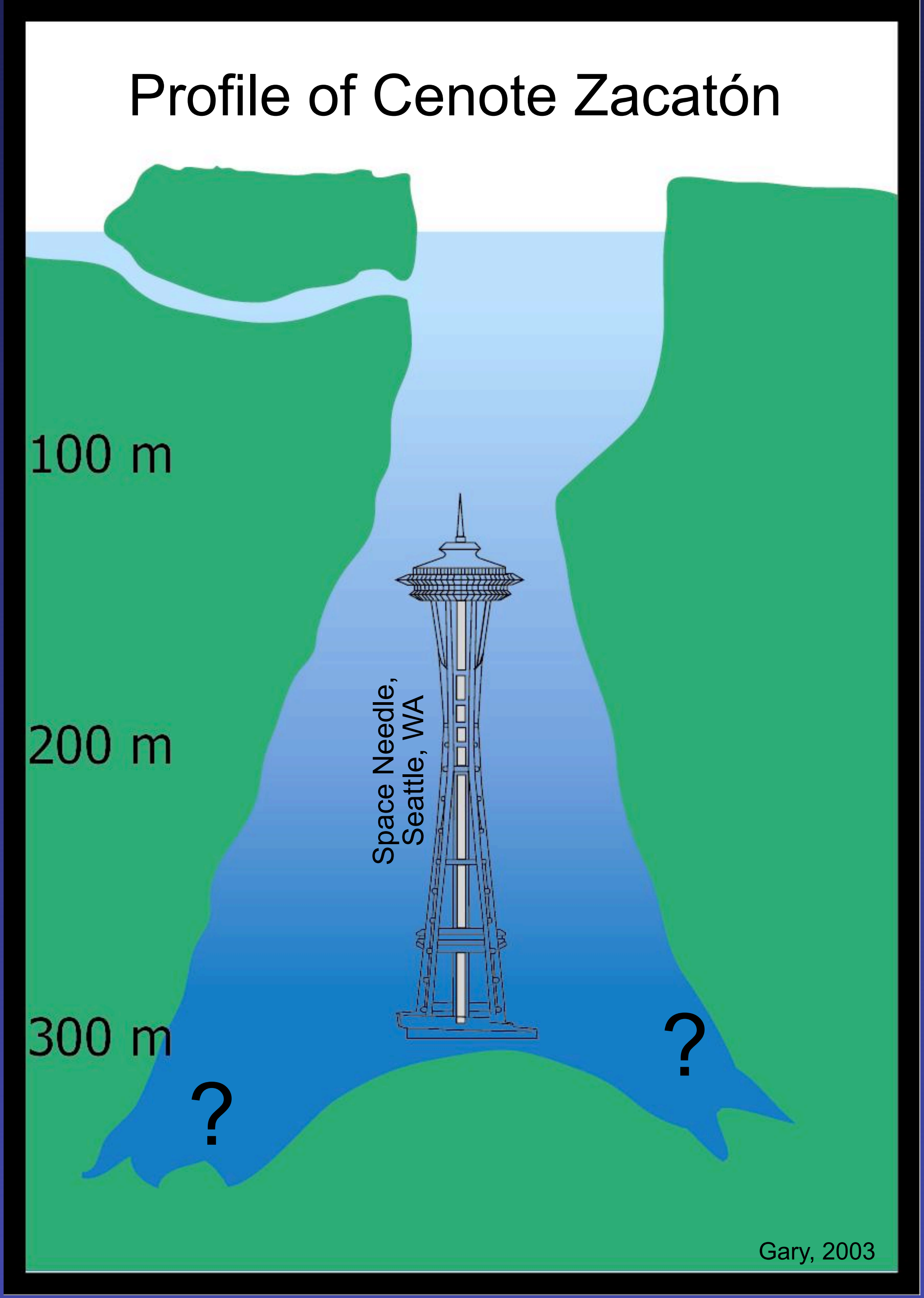
Zacatón

Max depth reached = 925 feet (280m)

Extent: unknown

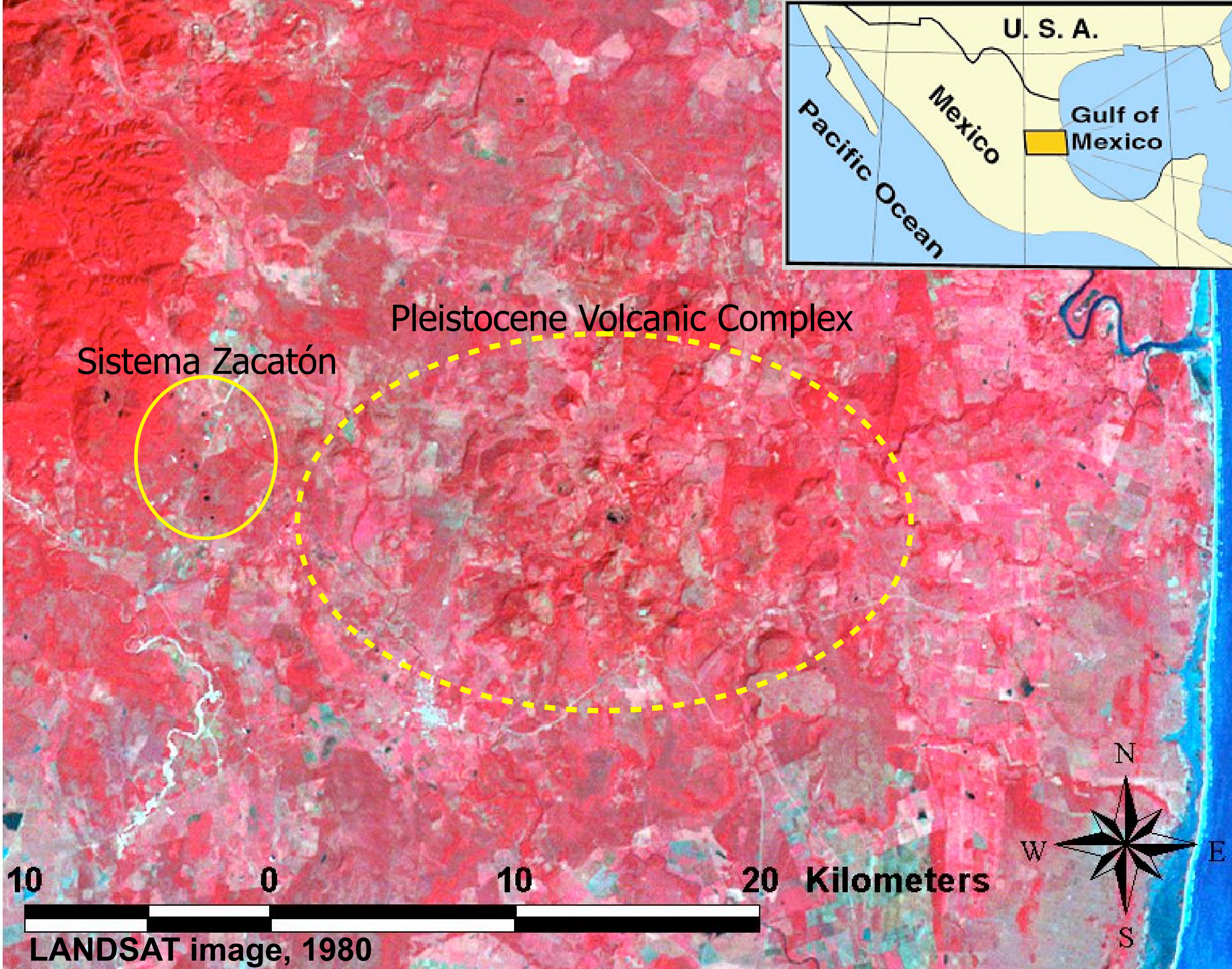
Limits: Beyond Human Reach

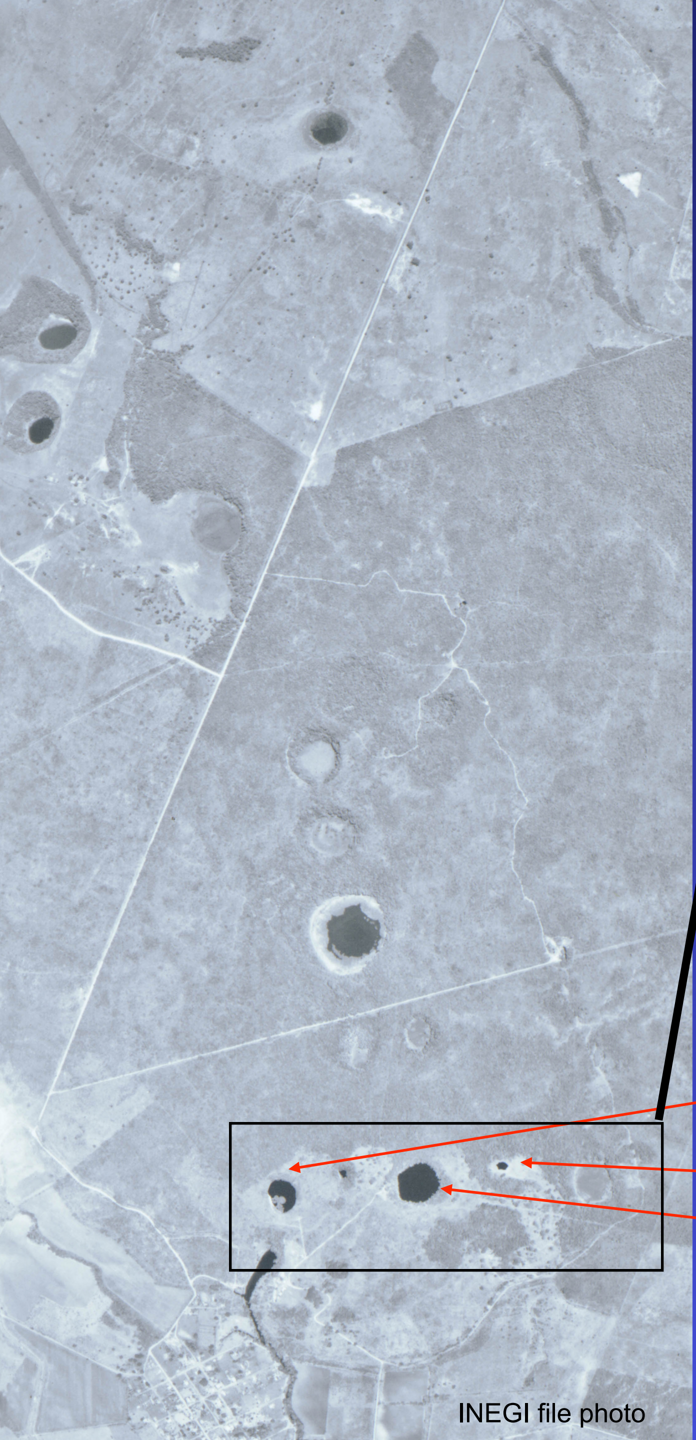
Photo by Peter Sprouse, 1999



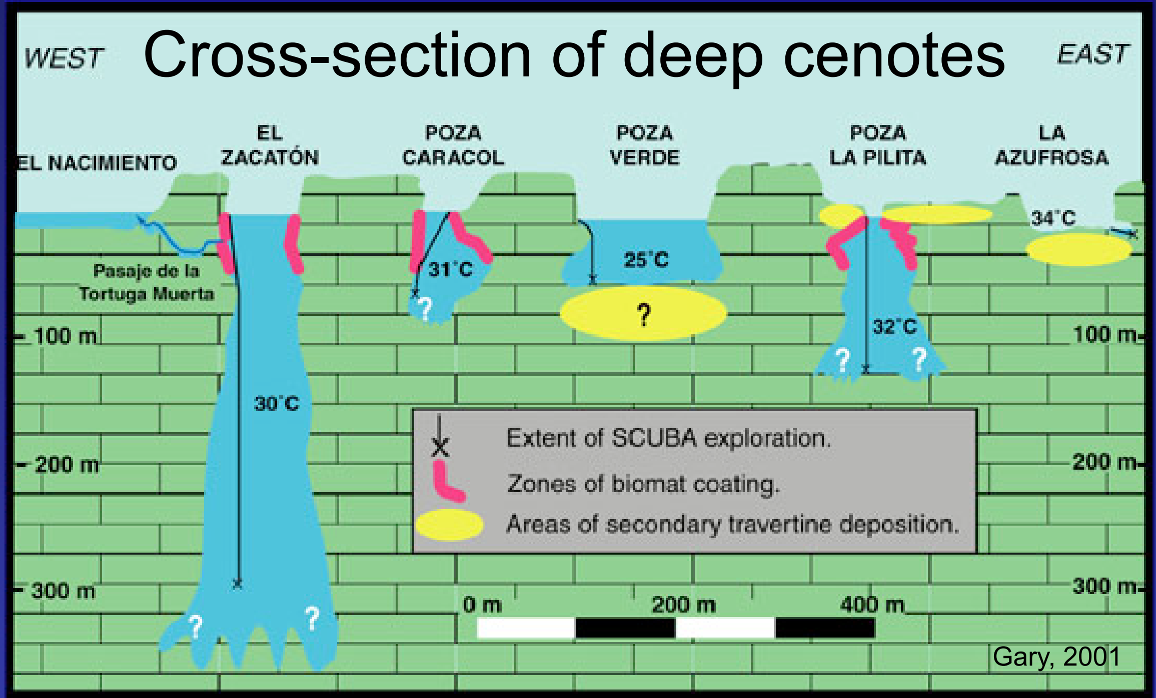
Hypothesized Profile based on limited spatial data

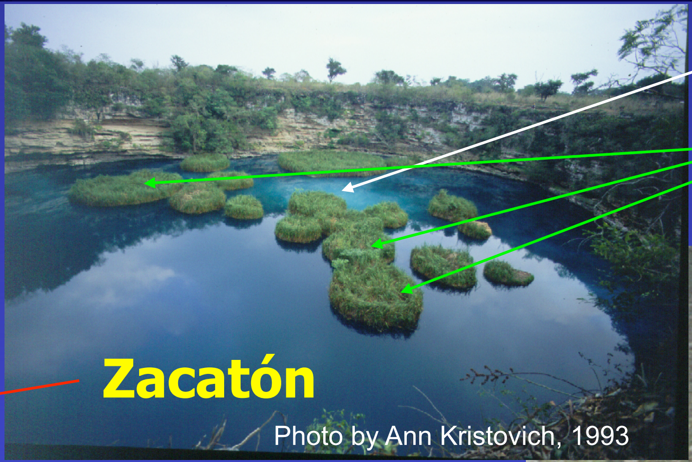
(wire drop sounding)

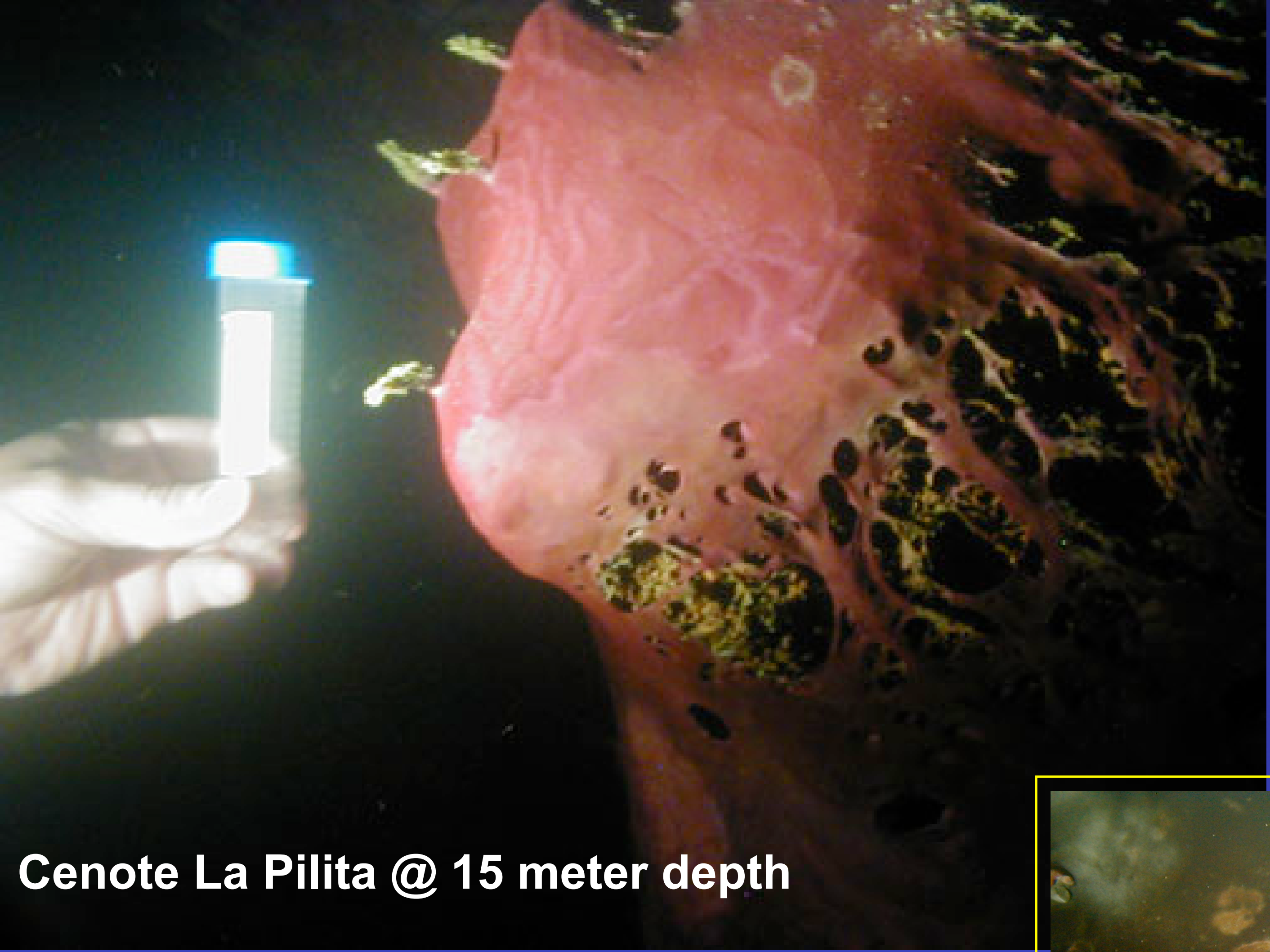

U. S. A.
Mexico
Pacific Ocean
Gulf of Mexico
Pleistocene Volcanic Complex
Sistema Zacatón
N
W
E
S
10 0 10 20 Kilometers
LANDSAT image, 1980



Cross-section of deep cenotes



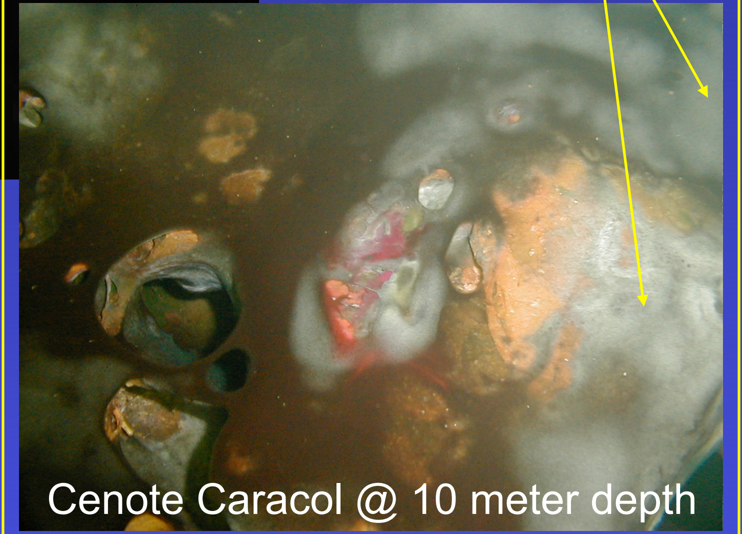




Cenote La Pilita @ 15 meter depth

Complex microbial communities have yet to be investigated

Apparent colloidal sulfur on biofilm

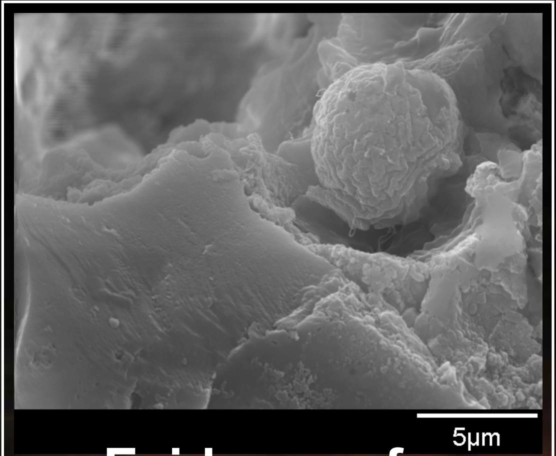


Cenote Caracol @ 10 meter depth

PURPLE BIOFILM COATS WALLS OF DEEPEST SINKHOLES IN PHOTIC ZONES – H_2O is anoxic and sulfurous.

Photos by Robin Gary, 2002

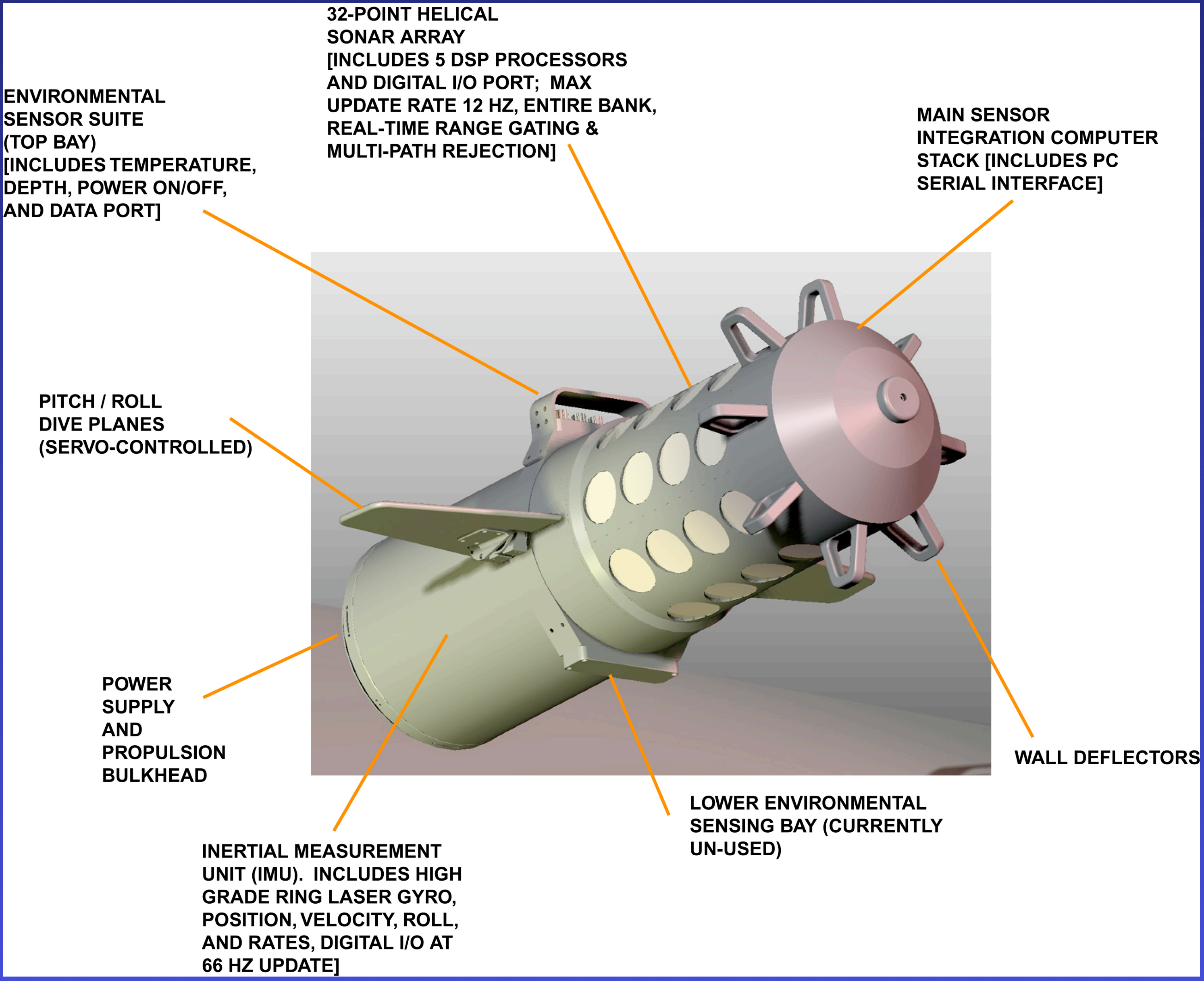
Biofilm covering subaqueous spar calcite in the cenote Caracol at a depth of 18 meters.

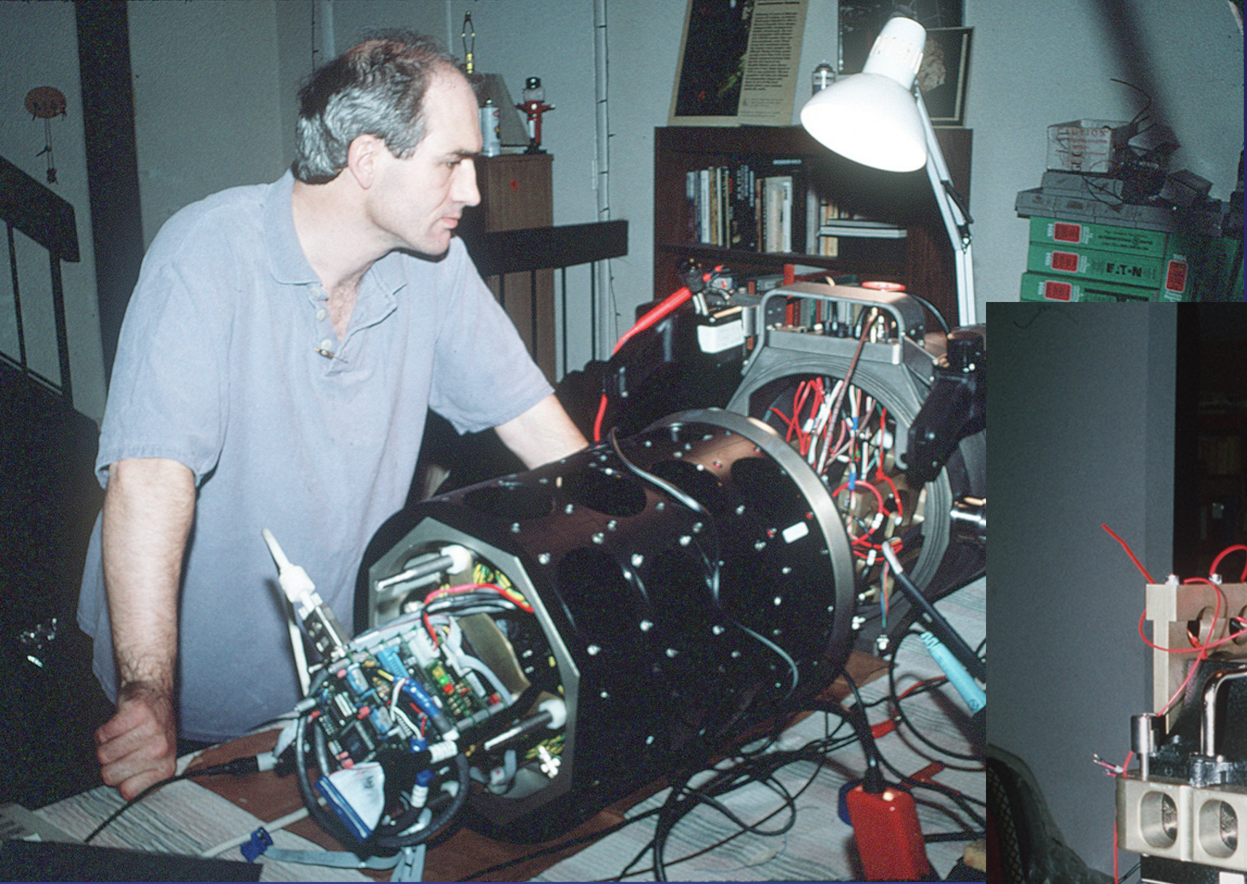


Evidence of microbial-mineral interaction imaged from calcite beneath biofilm

Photo by Robin Gary

Building DEPTHX:
heritage-proven technology





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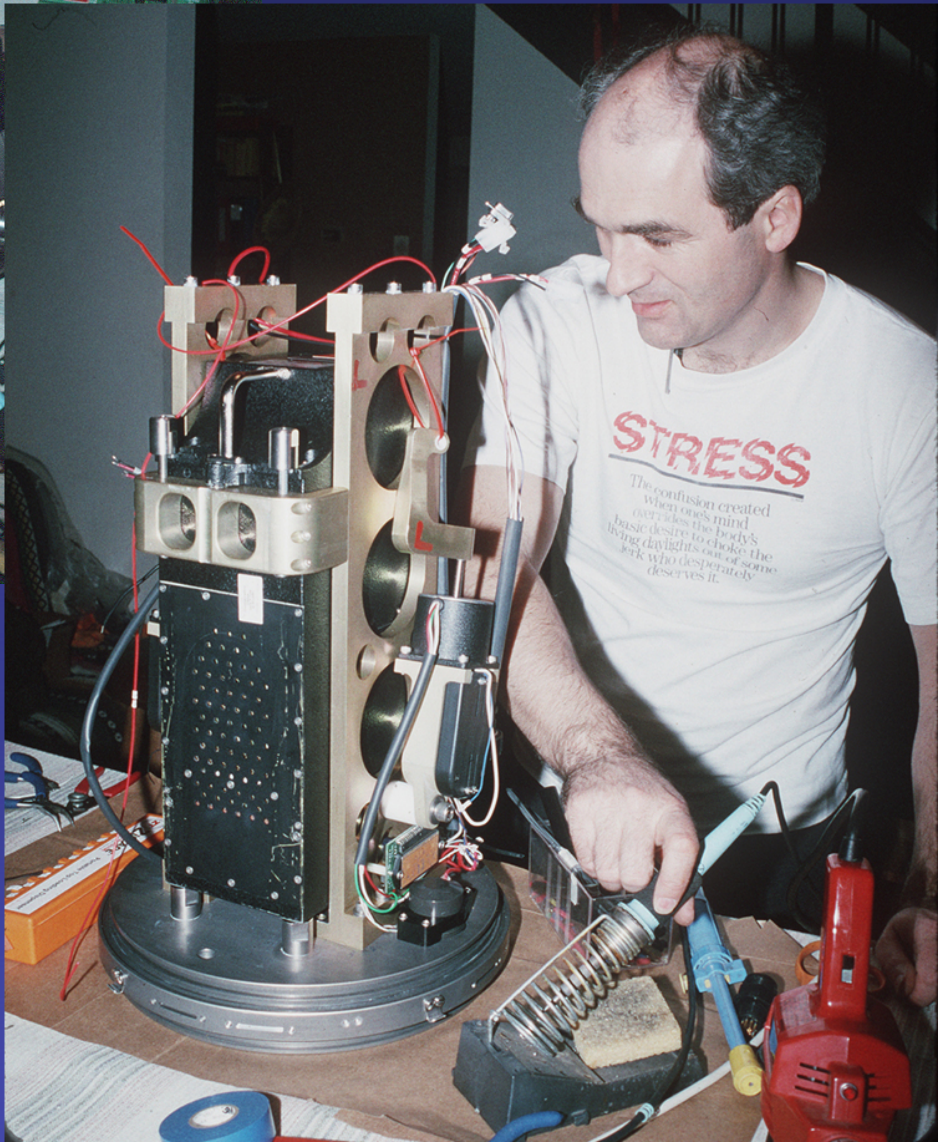
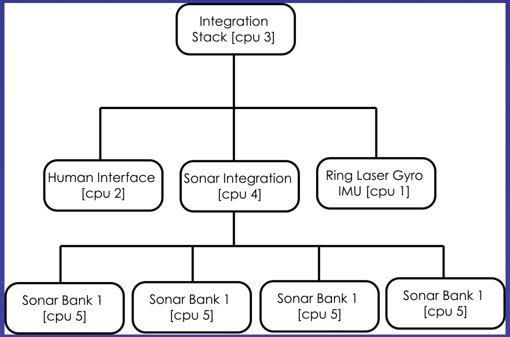




^ ^

32-point
Sonar
Array

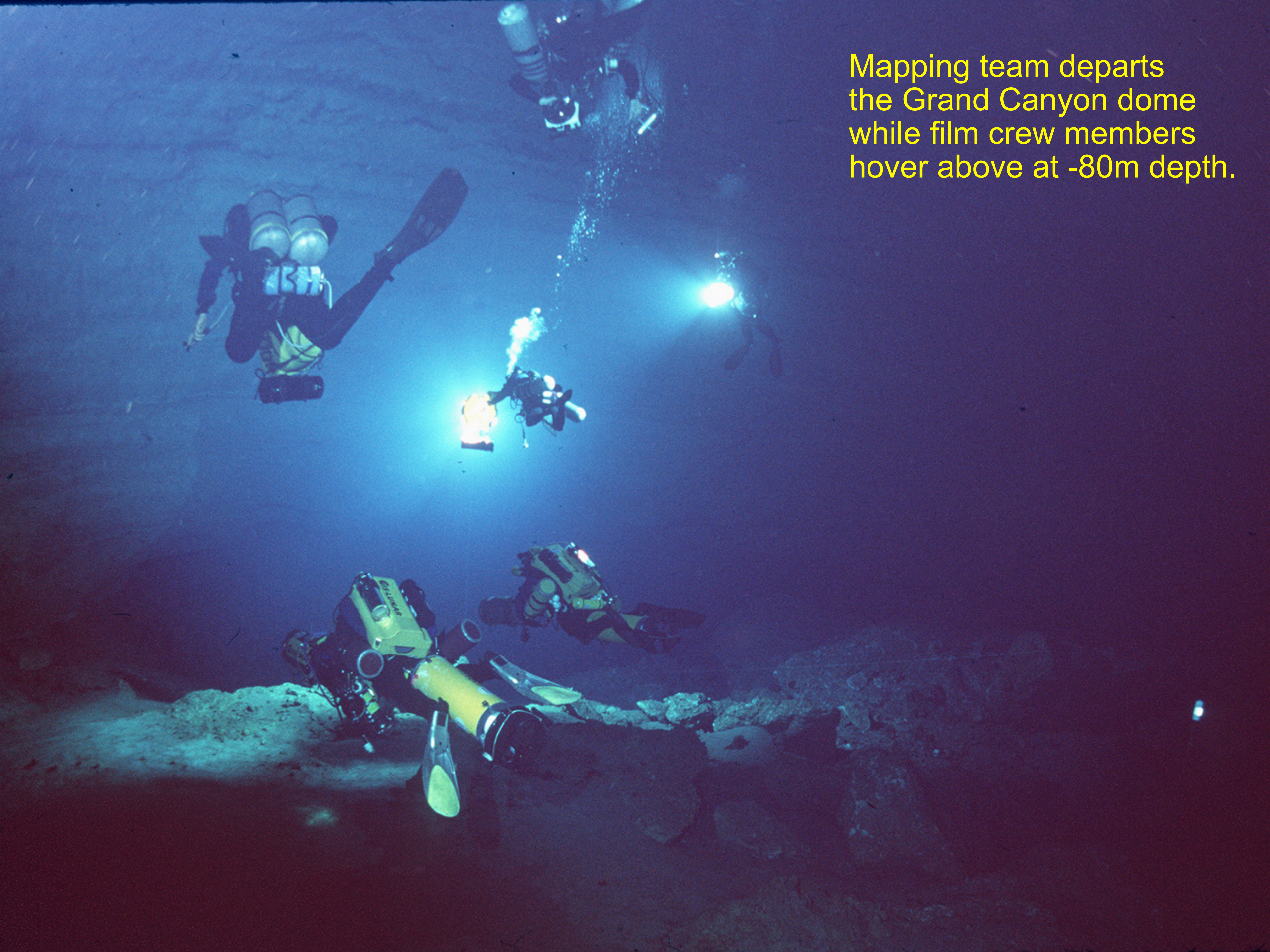
RLG / IMU

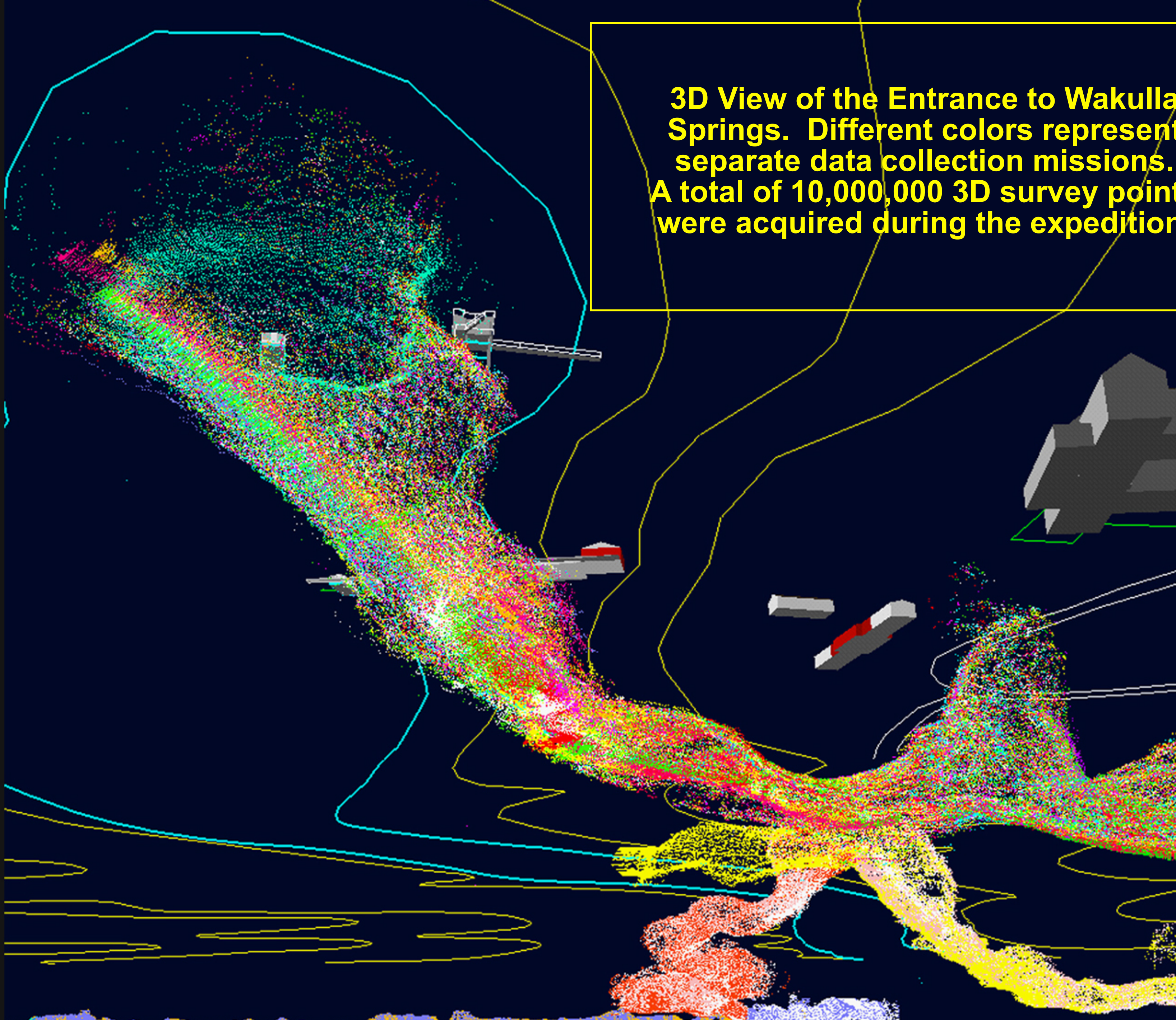
> >

Wakulla 2

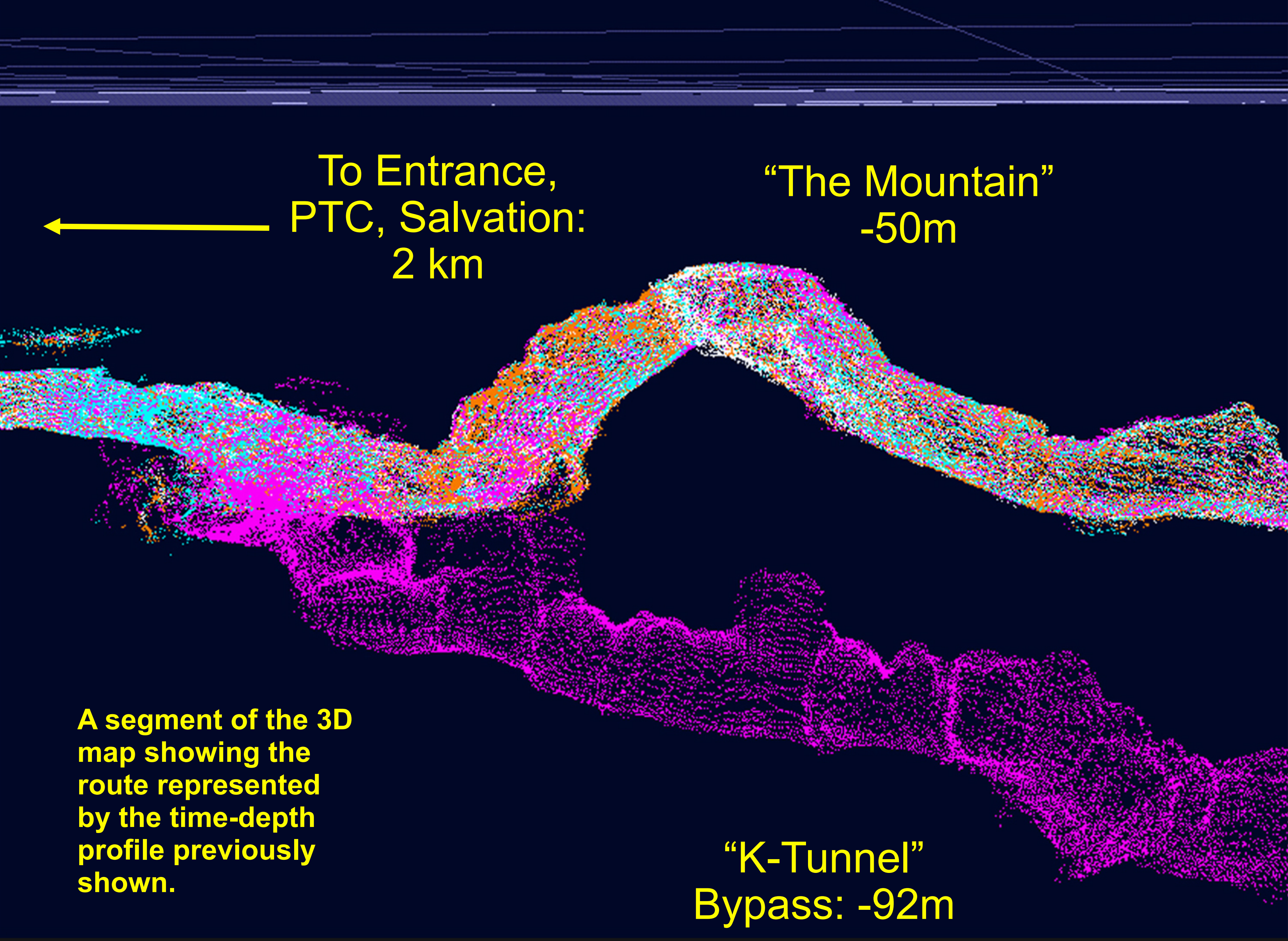
THE U.S. DEEP CAVING TEAM INC.


Typical Mapping Mission at
Wakulla Springs. Lead diver, with
MK5 backpack, drives the 3D mapper.
Support diver carries extra propulsion
units. Personnel transfer capsule
waits at upper left for pressurized
recovery of dive team at -30m.
CIS-LUNAR
CIS-LUNAR


Mapping team departs
the Grand Canyon dome
while film crew members
hover above at -80m depth.



3D View of the Entrance to Wakulla Springs. Different colors represent separate data collection missions. A total of 10,000,000 3D survey points were acquired during the expedition.


To Entrance, PTC, Salvation: 2 km
"The Mountain" -50m
A segment of the 3D map showing the route represented by the time-depth profile previously shown.
"K-Tunnel" Bypass: -92m

Wakulla 2
THE U.S. DEEP CAVING TEAM INC.

www.wakulla2.org

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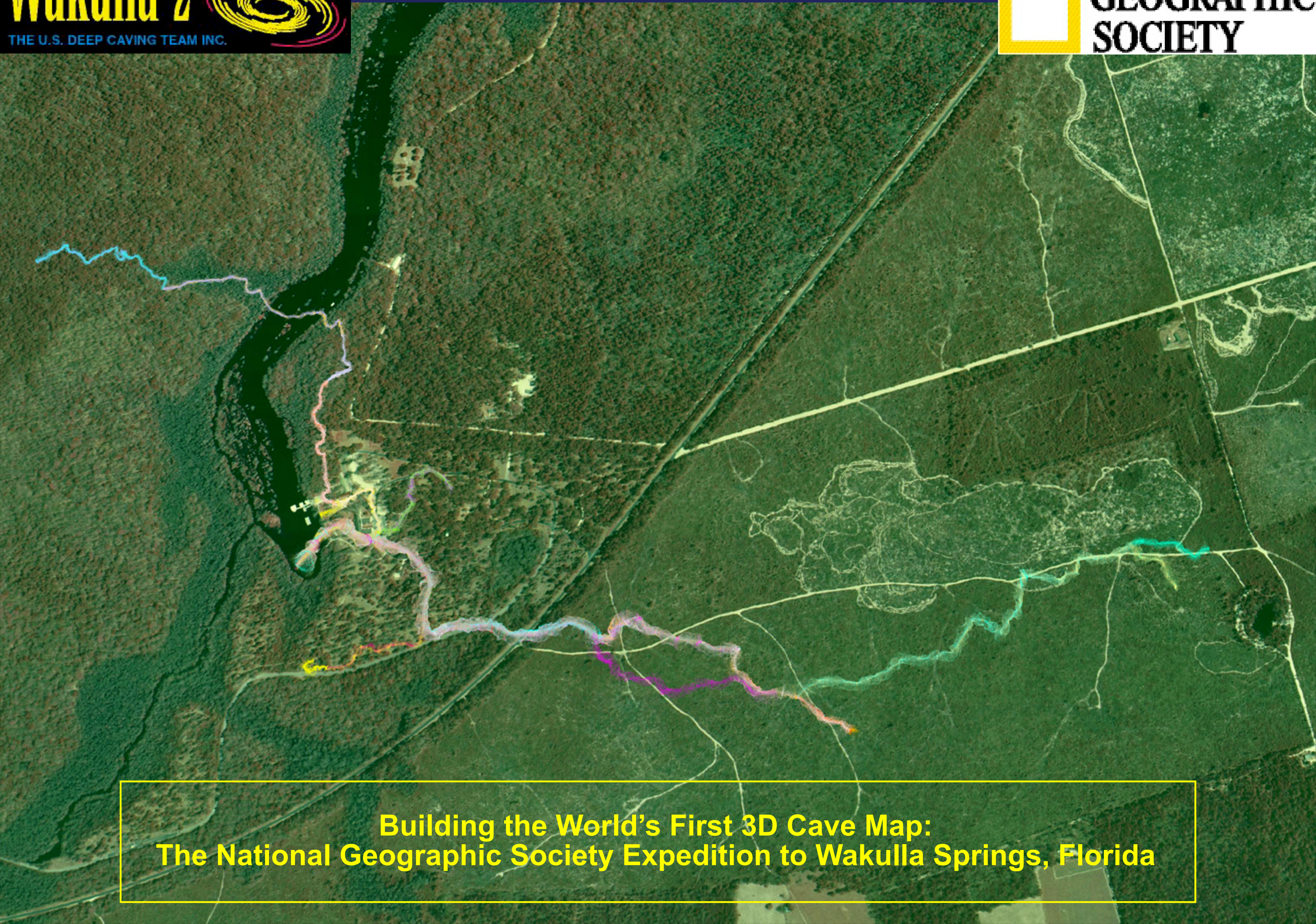
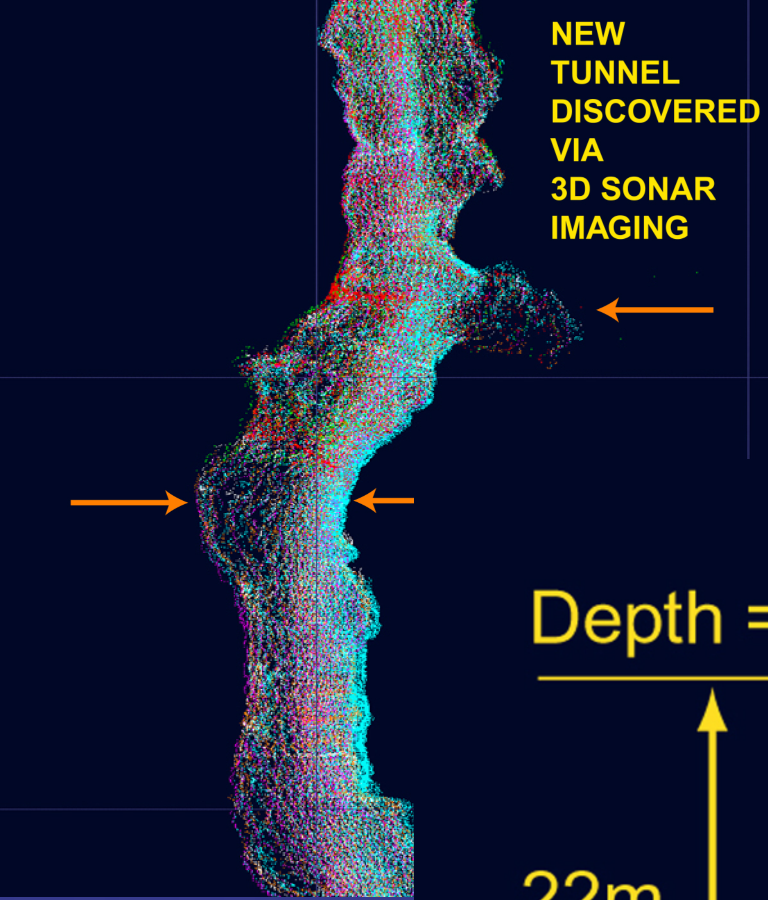
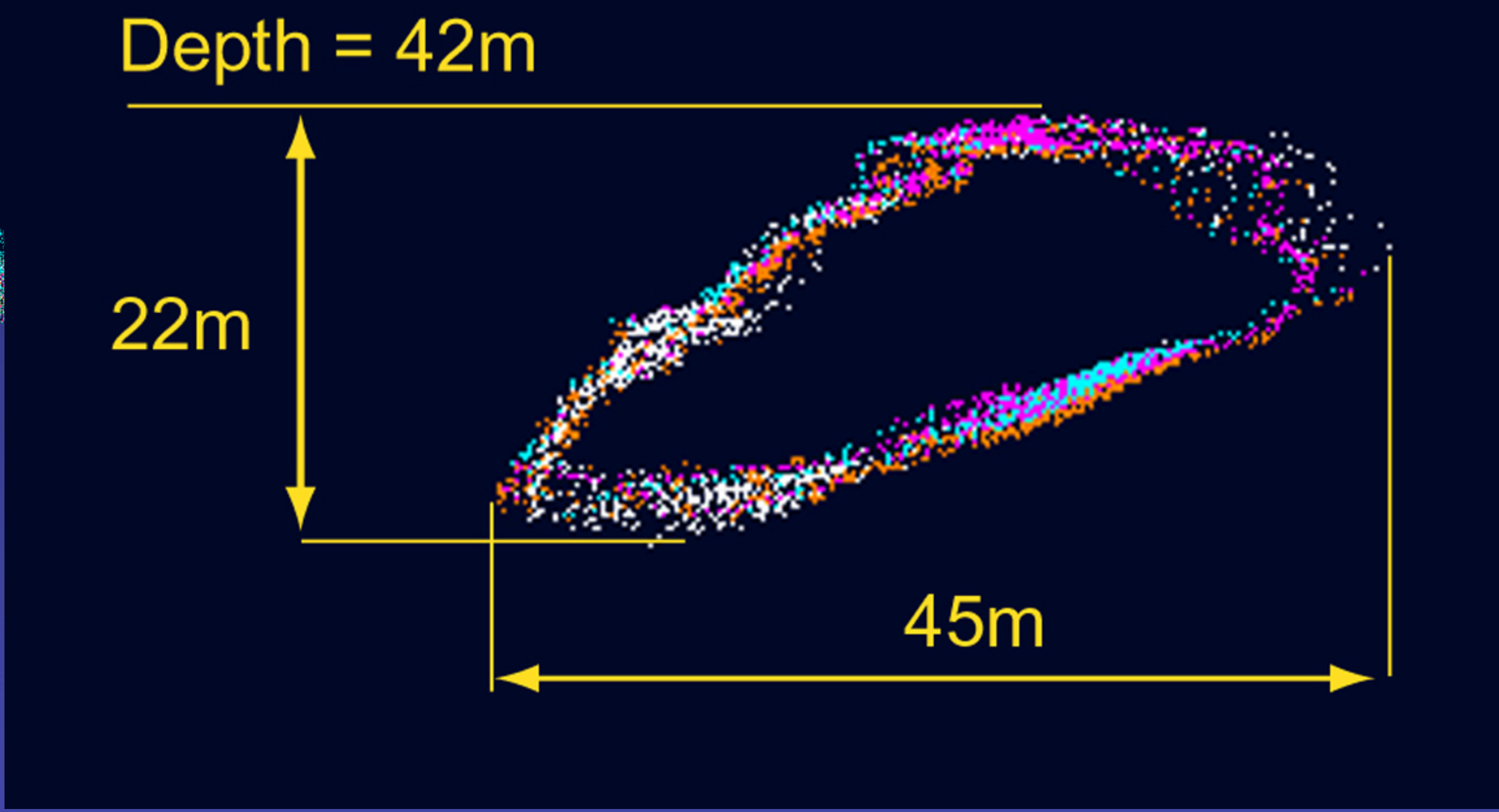


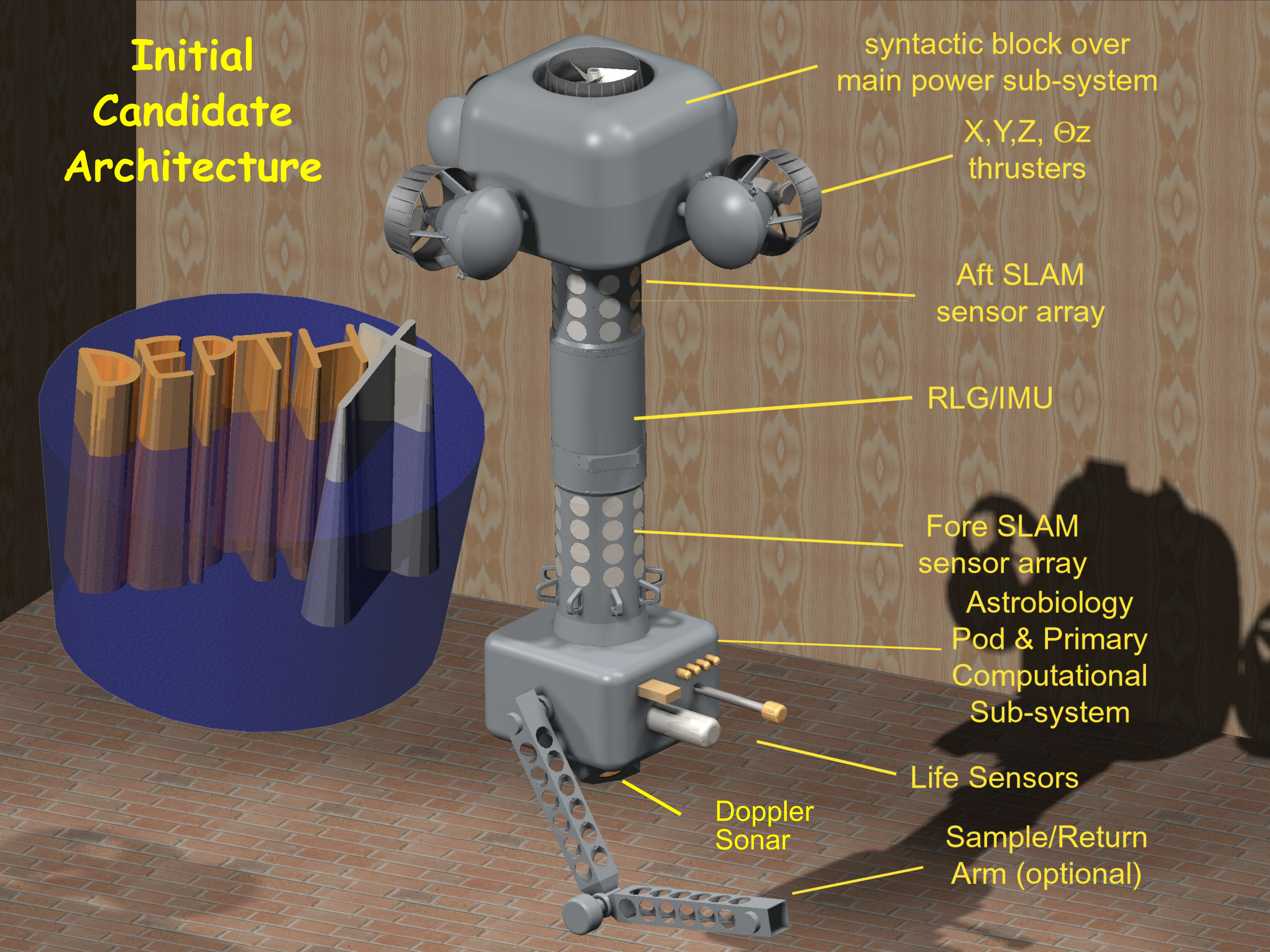
Building the World's First 3D Cave Map:
The National Geographic Society Expedition to Wakulla Springs, Florida

Registration of multiple mapping missions through magnetic induction waypoints: no such waypoints will be available on Europa



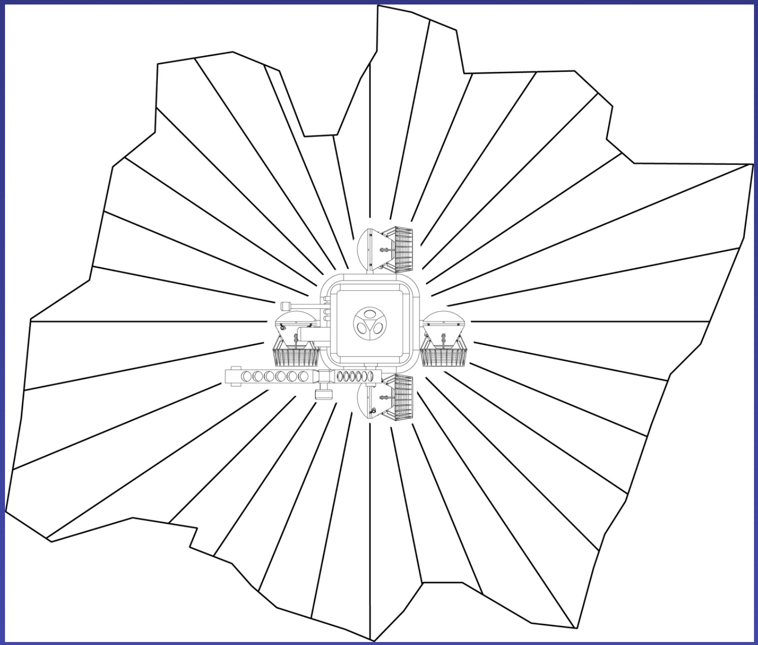


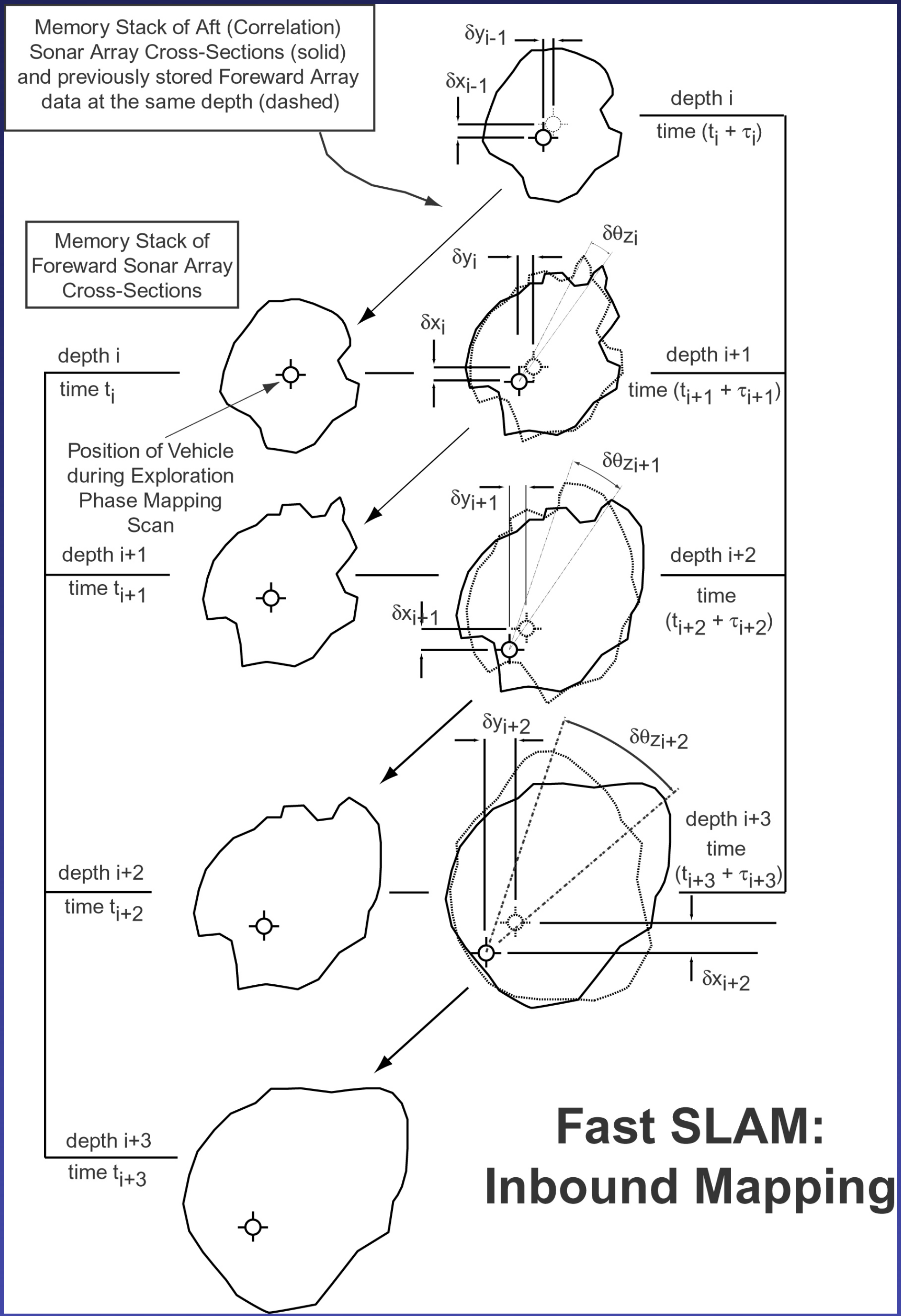
Mobility Platform: Phoenix LV

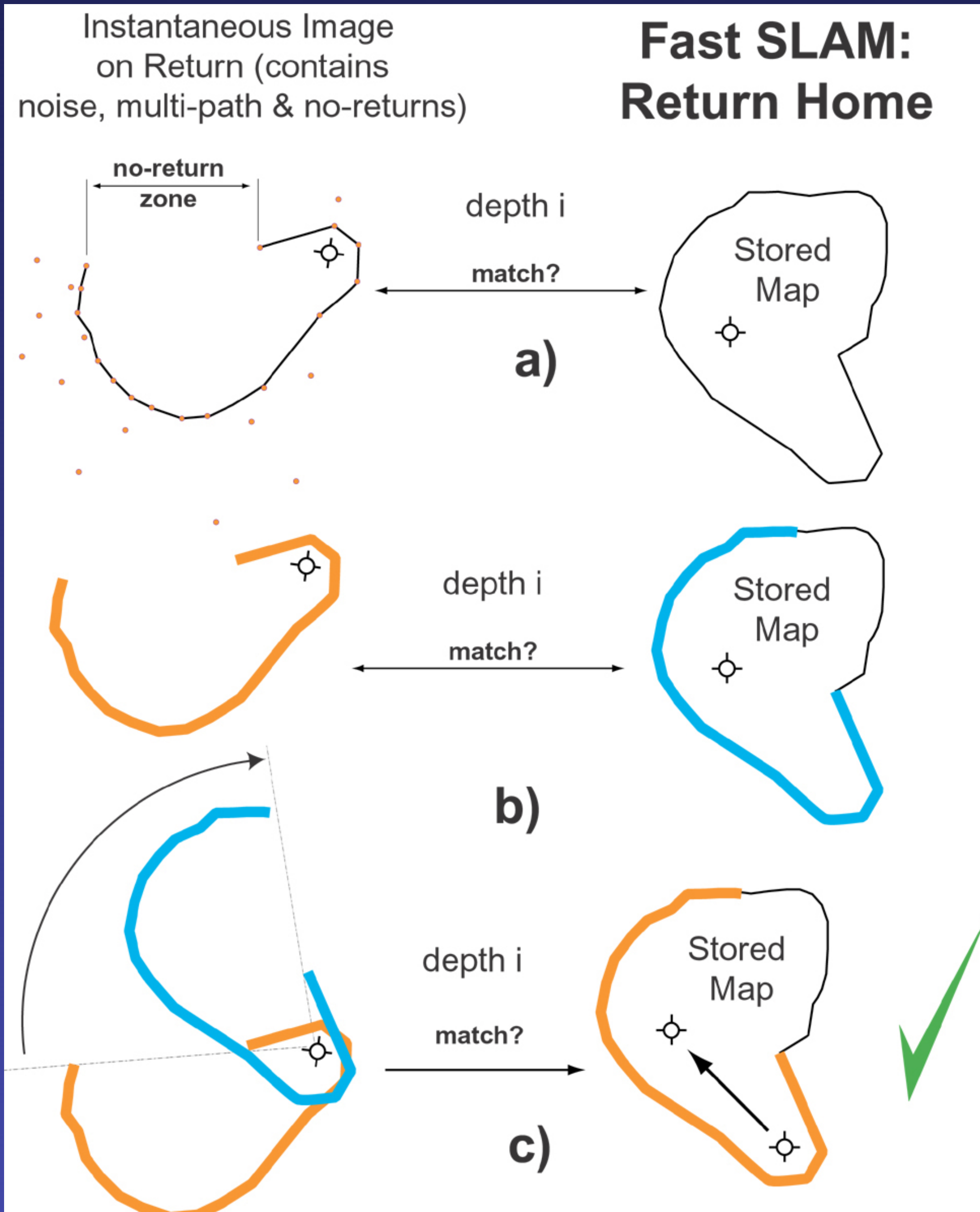

Initial
Candidate
Architecture
DEPTHX
syntactic block over
main power sub-system
X,Y,Z, Θz
thrusters
Aft SLAM
sensor array
RLG/IMU
Fore SLAM
sensor array
Astrobiology
Pod & Primary
Computational
Sub-system
Life Sensors
Doppler
Sonar
Sample/Return
Arm (optional)

Map Building & Navigation:

SLAM
IMU/RLG
DOPPLER SONAR
Depth







Return Home:

SLAM

IMU/RLG

DOPPLER SONAR

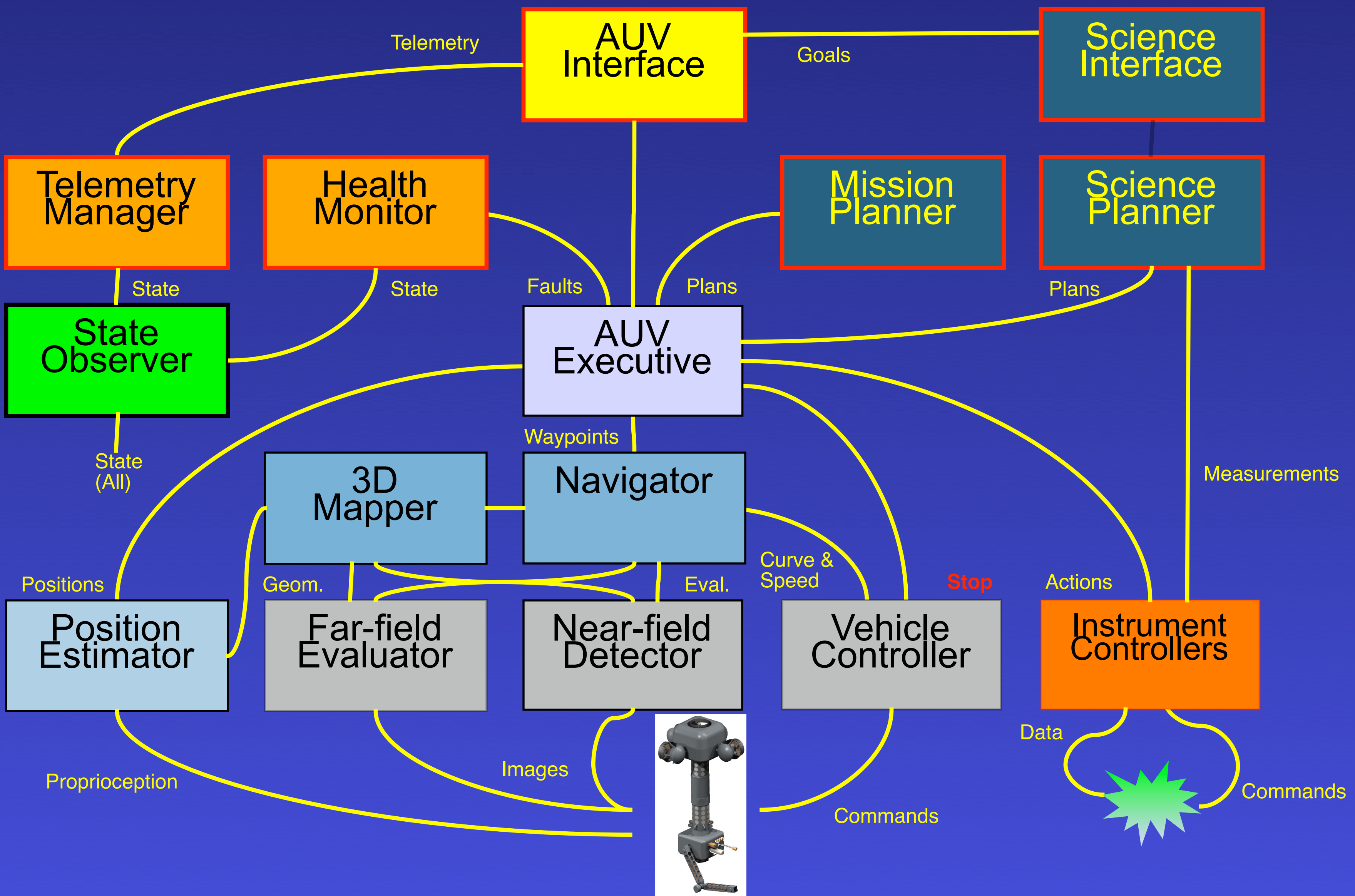
Depth

vs

Stored

3D Map

DEPTHX System Executive



Research Plan: Year 1

- Define sensor arrays, maneuvering system, mission planning algorithms, “return home” algorithms, on-the-fly segment co-registration algorithms
- Begin development of a completely integrated simulation package that will allow the performance of the fully-autonomous DEPTHX vehicle to be ascertained within the framework of existing 3D cavern datasets (mainly those from Wakulla Springs).
- Astrobiology team will define the basis for autonomous lifeform detection and the sensor suite and real-time software that will be required to implement it.

Research Plan: Year 2

- Continue SLAM & System Executive Development
- Manufacturing, Integration, and lab-testing of DEPTHX vehicle
- Field testing of SLAM and mission execution in controlled settings (collaboration with UT Applied Research Lab – Lake Travis, or Wakulla Springs)
- Lab-testing of Life Detection and Sample Subsystem

Research Plan: Year 3

- Zacaton field campaign (3-4 months on site)

- Field Campaign Goals
  - Autonomous mapping of unknown territory to -500m at 1,000m+ from entrance
  - Ability to discriminate among biological control samples (collected prior to mission by divers)
  - Autonomous Collection of novel lifeforms